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Influence of Artificial Saliva on the Corrosion Behavior of Dental Alloys: A review

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ABSTRACT

To regulate the growth of teeth, people are implanted with orthodontic wires made of different materials. These are exposed to the influence of oral environment, food intake, toothpastes, and mouthwashes. During this process, the materials may undergo corrosion. Hence, various researchers have made a study on the influence of artificial saliva (AS) on the corrosion behavior of these alloys. The excellent corrosion resistance to the oral environment of dental alloys is important for biocompatibility as well as for orthodontic appliance durability. Various types of metal alloys are being used for the orthodontic treatment, which undergo chemical or electrochemical reaction with the oral environment. The oral environment is highly aggressive under several situations and leads to corrosion. This article reviews the effects of fluoride concentration, the pH value and protein content in AS and the composition of the metal alloys on the corrosion resistance of orthodontic appliances using electrochemical methods and surface characterization techniques such as scanning electron microscopy and X-ray diffraction.

Key words: *Alloys***,** *Electrochemical methods, Scanning electron microscopy, X-ray diffraction, Corrosion, Aggressive.*

1. INTRODUCTION

Dental implants are manufactured using metallic materials. They have to exhibit high corrosion resistance to prevent metal release in the oral environment. Oral cavity represents a multivariate environment with a wide range of conditions including broad range of temperatures, pH, and the presence of bacteria and effect of abrasion [1].

Depending on the environment of mouth the traces of corrosion on the surfaces of metals used in any application can be observed after a period [2]. Dental alloys in a mouth are exposed to the influence of chemical, biological, mechanical, thermal, and electrical forces. These forces substantially lessen their durability by a negative effect on functional and esthetic characteristics of dental works. Electrochemical corrosion is the most important damaging factor of dental works [3]. Corrosion is the unintentional wearing down of the metal surfaces. By exposure to chemical or electrochemical reaction of the surrounding area, the outer and inner layers of the metallic surface get damaged [4]. The electrolyte is needed for electrochemical reaction. Saliva has the role of electrolyte in the mouth. Saliva is a media of strong corrosive effect. As its pH factor decreases and as chloride concentration increases, the increase in corrosion potential of saliva is observed.

The corrosion process occurs, as a result, either of the loss of metal ions directly into the solution or the dissolution of the surface films.

The stainless steel, cobalt-chromium, and titanium alloys used in orthodontic appliances rely on the formation of passive surface oxide films to resist corrosion. The protective layers formed on the surface of these alloys are not reliable as they are susceptible to both mechanical and chemical degradation. Even without destruction, oxide films often slowly dissolve only to reform as the metal surface is exposed to oxygen from the air or the from surrounding medium [5]. The acidic drinks and foods, containing sodium chloride are corrosive materials. The process of corrosion is accelerated by the aggressive media such as chloride ions and acidic conditions. It is further enhanced by the fluoride ions in toothpaste and in the products used as mouthwash as it plays the role of an important factor accelerating corrosion [5-9].

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Corrosion resistance of biomaterials made up of various metals and alloys has been investigated in artificial saliva (AS); various metals and alloys such as Ti-Co alloy [10], Ti30Ta alloy [11], Ti metal, Ti6-Al-7Nb, and Ti-6Al-4V alloy [1,12], Ti-6Al-7Nb alloy [13], Co-Cr alloy [14-18], CP-Ti and Ni-Cr-Ti alloy [19], Co-Cr-Mo alloy [20,21], Ni-Cr alloy [18,22,23], Ti-Cu [24], Ti-20Zr alloy [25], Ti12Mo and Ti60Ta [26], Ni-Ti shape memory alloy and stainless steel wire [27], and Ti-Mo [28].

Corrosion resistance of various metals has been investigated in AS [1-32]. The corrosion resistance of metals and alloys in AS and biological solutions has been reviewed recently [33,34].

1.1. Medium

Usually, corrosion behavior of metals and alloys have been studied in AS whose composition is given in Table 1 [35].

In some studies AS containing fluoride [19,36], hydrogen peroxide [23], NaF [1,11], and albumin proteins [11,27] have been used.

1.2. Temperature

The study is carried out at 37±1°C.

2. EXPERIMENTAL

Polarization study, AC impedance spectra have been used to evaluate the corrosion resistance of various metals and alloys in AS [1,10-13,19,24]. The protective film formed on the surface of the metal has been analyzed by various surface analysis techniques such as scanning electron microscopy (SEM) [1,11,14], X-ray diffraction [1], and Fourier series expansion method [19]. The metal ions released from dental alloy were detected by inductively coupled plasma mass spectrometry [23].

3. RESULTS AND DISCUSSION

3.1. Effects of the Fusayama AS

The corrosive effect of the artificial saliva-based solutions is due to the presence of chloride ions. If the environment contains certain amounts of chloride ions, then they lead to the formation of pitting corrosion. It is a form of symmetrical localized corrosion in which pits form on the metal surface. It usually occurs in the base metals, which are protected by a naturally forming thin film of an oxide. It locally breaks down and rapid dissolution of the underlying metal occurs in the form of pits in the presence of chlorides in the environment. The existence of chloride ions in the saliva solutions causes pitting corrosion is well visible in the experimental studies after SEM examinations of the surface of metals and alloy. Evidence of pitting corrosion formed on the wire surface is shown by Stainless steel [27], Co-Cr [14-18], Ni-Cr [18,22,23], Ni-Ti [27] exposed to electrochemical study.

Table 1: Composition of artificial saliva (Fusayama Meyer).

Name of compound	Weight g/L
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

3.2. Effects of Fluoride Ion on Corrosion Resistance of Dental Alloys

Fluoride is added in toothpastes and in the products used as mouthwash to strengthen and enhance the lifetime of the teeth. This addition of fluoride may affect the strength of dental alloys. To know these effects, several investigations were undertaken. Corrosion resistance of metals and alloys in AS, in the presence of fluoride has been investigated [1,10,11,12,14,19,24,36-39].

The presence of fluoride ions (added as NaF), significantly affects the corrosion behavior of Ti metal, Ti-6Al-7Nb, and Ti-6Al-4V alloys and constituent metals in AS as proven by electrochemical methods [1]. All the titanium alloys in fluoridated acidified saliva show an active behavior due to the presence of significant concentrations of HF and HF^{2-} species that dissolve the spontaneous air-formed oxide film giving rise to surface activation [13].

Cheng *et al.* analyzed the corrosion resistance of cobalt-chromium alloy, pure titanium, and high-cobalt chromium molybdenum alloy immersed in AS with different concentrations of fluoride by studying the changes in surface morphology and he observed that the metal surface roughness was increased with the concentration of fluoride [14].

Various electrochemical methods were used to examine the effect of fluoride ion concentration on the corrosion behavior of Ti and Ti6-Al-4V implant alloys, in AS when coupled with either metal/ceramic or all ceramic superstructures. This lead to the conclusions that while fluoride concentration increases corrosion resistance of Ti and its Ti6-A1-4V alloy decreases [12]. Ti-Co alloy [10] and Ti-Cu alloy [24] gave similar results. Surprisingly, the presence of Ta in the Ta30Ta alloy has a beneficial effect on its behavior in acidified fluoridated AS [11]. The corrosion resistance of pure titanium in AS containing fluoride ions decreased was observed by Liang *et al*. [19].

3.3. Effect of Hydrogen Peroxide on Corrosion Resistance of Dental Alloys

The effect of hydrogen peroxide on the electrochemical corrosion and metal ions release of nickel-chromium dental alloys was investigated by Wang and Qiao. They observed that the sequence of charge transfer resistance (R_{ct}), corrosion potential (E_{corr}), pitting breakdown potential (E_b), and the difference between E_{corr} and E_b representing the "pseudo-passivation" (δE) of nickel-chromium alloys in AS was 30% <10% <0% (P<0.05). Furthermore, the metal ions including Ni, Cr, and Mo were released from the Ni-Cr alloys to the AS, and the order of the concentrations of metal ions was 0%<10%<30% (P<0.05). Nickel-chromium dental alloys are more prone to corrosion in the AS. As the concentration of hydrogen peroxide increases more metal ions are released in the AS and the corrosion resistance of nickel-chromium dental alloys decreased after immersed in different concentrations of hydrogen peroxide for 112 h [23].

3.4. Effects of Chemical Composition on Corrosion Resistance of Dental Alloys

The effect of the oral environment on the corrosion of dental alloys with different compositions, using electrochemical methods was studied by Galo *et al.* He observed that the dissolution of the ions occurred in all tested dental alloys, and the results were strongly dependent on the general alloy composition. Regarding the alloys containing nickel, the Ni-Cr and Ni-Cr-Ti alloys released 0.62 mg/L of Ni on average while the Co-Cr dental alloy released ions between 0.01 and 0.03 mg/L of Co and Cr, respectively. The open circuit potential stabilized at a higher level with the lower deviation (standard deviation: Ni-Cr-6Ti=32 mV/SCE and Co-Cr=54 mV/SCE). The potentiodynamic curves of the dental alloys showed that the Ni-based dental alloy with >70 wt% of Ni had a similar curve and the Co-Cr dental alloy showed a low current density and hence a high resistance to corrosion compared with the Ni-based dental alloys [40].

3.5. Effect of pH on Corrosion Resistance of Dental Alloys

Many metals and alloys undergo corrosion at lower pH, because of acidic environment. Similar results are observed in the case of dental alloys in the oral environment. Corrosion resistance of Ti-Co alloy decreased with low pH value. According to Mott-Schottky analysis with decrease in pH value of AS, the defect density increased [10]. The effect of pH value on the corrosion resistance of pure Ti and Ni-Cr-Ti alloy in the AS was investigated by Liang *et al*. He observed that with the lower pH value, the E_{corr} and I_{corr} of pure titanium and Ti-Ni-Cr alloy increased, the Rp decreased and the corrosion resistance of pure titanium and Ti-Ni-Cr alloy was decreased with decrease in pH value [19].

3.6. Effects of Protein on Corrosion Resistance of Dental Alloys

Protein addition to the AS had a significant influence on the corrosion behavior of composite arch wires (CoAW) with Cu interlayer between NiTi shape memory alloy and stainless steel wire. Low concentration of protein caused the corrosion resistance of CoAW decrease in electrochemical corrosion and immersion corrosion tests. High concentration of protein could reduce this effect [27].

4. CONCLUSIONS

The primary requisite of any dental alloys is that they must not produce corrosion products that will be harmful to the body. The corrosive resistance of metal is its important characteristic during implantation into a mouth. Several metals and alloys are used in orthodontic treatment. Hence, it is essential to know the corrosion resistance of these materials in AS;

- The existence of chloride ions in the saliva solutions causes pitting corrosion
- Corrosion resistance increases with high protein content in saliva
- pH-4 value of saliva increases the corrosion resistance
- The chemical composition of the alloys, hydrogen peroxide, and fluoride concentration in saliva play significant role in corrosion resistance of dental alloys.

5. SIGNIFICANCE

This study will be useful to the researchers to know the work that has been already done in evaluating the corrosion resistance of materials in AS so that they can go further in this research. This is also useful to the dentists to recommend the appropriate orthodontic wires to their patients and suggest the necessary precautions. The patients who are implanted with these orthodontic wires are aware of their effects in the oral environment.

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***Bibliographical Sketch**

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Professor Dr. Susai Rajendran has been serving the student community for the past 43 years as Professor of Chemistry. He is still continuing his research activities in the field of corrosion and its control, green inhibitors, concrete corrosion, corrosion resistance of metals and alloys in various body fluids, synthesis and characterization nano particles, electroorganic synthesis, etc. He has received national meritorious award in the field of corrosion, twice, from NACE, India Section. He has authored 3 books and 1 patent. He has published more than 300 papers in reputed journals and produced 30+ PhD degree holders. Previously has worked GTN Arts College, Dindigul; Servite College of Education for woman, Thogamalai; RVS School of Engineering and Technology, Dindigul, India. Presently, he is serving as Professor of Chemistry and research director at Department of Chemistry, St. Antony's College of Arts and Science for women, Amala Annai Nagar, Dindigul. He feels that his strength and wealth. He is standing on the shoulders of his students. He is taking research toward the down trodden and the youngest.