A Review

Corrosion of Orthodontic Wires: Review Article

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Abstract

Corrosion has been found to be the predominant cause for the failures of many metallic orthodontic archwires. Corrosion occurs due to the loss of the metal ions into the solution directly or due to the protective surface oxide layer degrading slowly. There is a simultaneous oxidation and reduction process taking place also called as redox reaction. Corrosion causes a breach in the protective oxide films which enables the beginning of the corrosive process. With evolution in metallurgy, different types of orthodontic archwires have come into use which has different physical and chemical properties. In the oral cavity, orthodontic archwires are subjected to both physical and chemical damage which acts in combination to degrade physical properties and increase the potential for failure. These corrosive chemical reactions may occur due to different kinds of mouthwashes such as chlorhexidine, sodium fluoride mouthwash etc.

The corrosion of different metallic archwires can be studied using photographs generated from Scanning Electron Microscope.

The review article aims to understand about the corrosion of orthodontics wires when they are at normal oral condition, temperature changes and lastly the interventions using mouthwash or dentifrices

INTRODUCTION

Archwires used in orthodontic practice are available in several types and compositions ranging from alloys of Stainless Steel, Nickel-Titanium, Titanium-Molybdenum Alloy, Coated archwires, Copper NiTi wires, Australian wires etc. The archwires are exposed to intra oral environment which is corrosive due to presence of saliva, variability of pH and temperature[1]. Stainless Steel was introduced as an orthodontic wire in 1929, and because of its superior strength, higher modulus of elasticity, good resistance to corrosion, and moderate costs[2]. However, hydrogen embrittlement occurs in fluoride solutions and due to this, stress corrosion cracking of stainless steel has been reported in fluoride solution[3].

Nickel-titanium (NiTi) alloys were introduced into clinical use in 1972. It was produced under the trade name Nitinol, with a composition of 55% nickel and 45% of titanium. In 1985, a new super-elastic NiTi alloy, developed especially for application in orthodontics, was reported. NiTi alloys have good spring back and flexibility[4]. Ni ions released due to corrosion can cause allergies, toxicity and carcinogenicity. NiTi archwires are significantly more stable and resistant to corrosion than stainless steel arch-wires[5].

In 1979, Goldberg and Burstone6 introduced for the first time a beta-titanium (b-Ti) alloy into orthodontic applications due to its biocompatibility, low stiffness and resistance to corrosion[3, 4]. Due to its high chemical reactivity, titanium forms a thin stable oxide layer when exposed to air. This phenomenon is called as passivation. Titanium protective film reacts with hydrofluoric acid (HF) to form sodium titanium fluoride. The breakdown of the film leads to a decrease in corrosion resistance because titanium shows intrinsically high reactivities[3].

NiTi-Cu is composed, basically, of 42.99% Titanium, 49.87% Nickel and 5.64% Copper. The addition of Copper in NiTi-Cu archwires increases potential reduction[6]. When a chemical bond immersed in a solution and/or contact with oxygen, the electrochemical processes of corrosion occurs[7].

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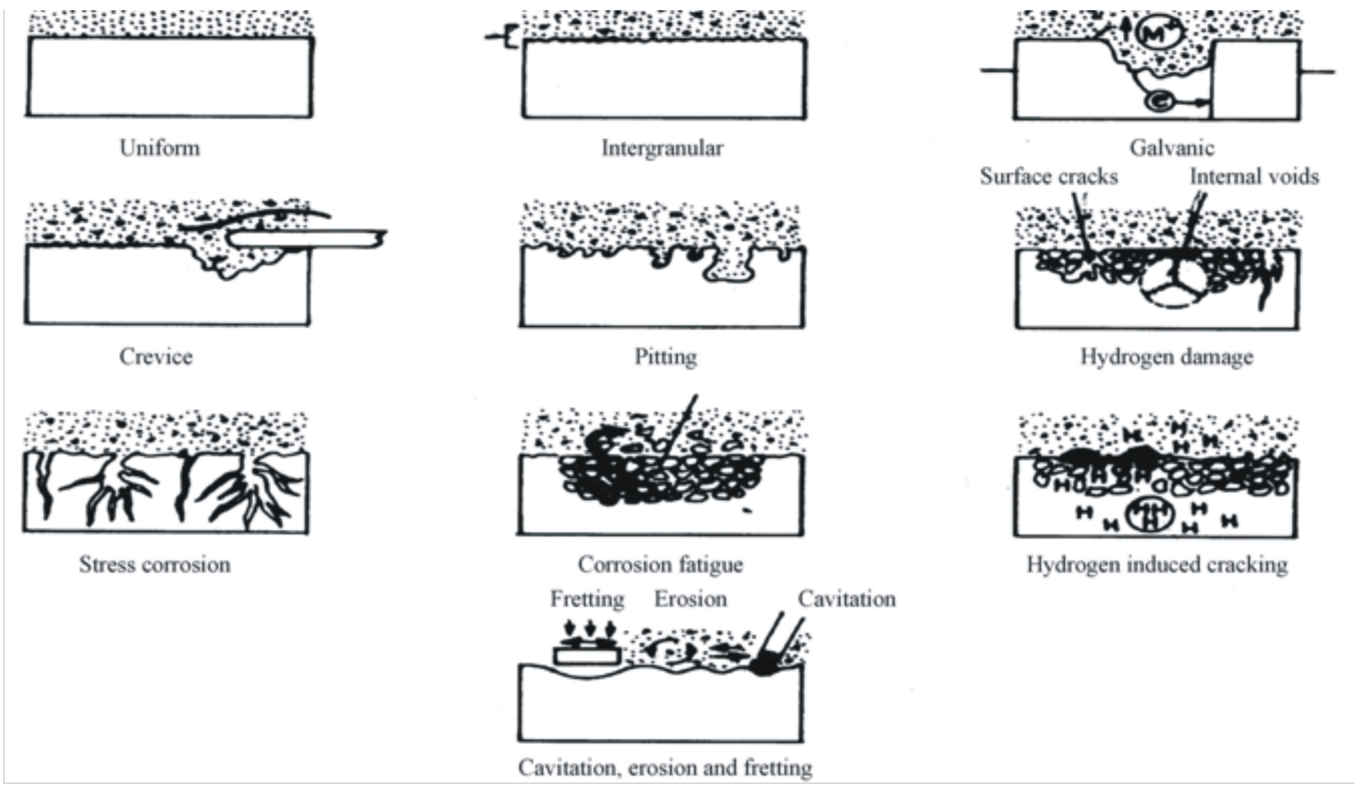
NiTi wires with epoxy resins and nitride coatings have been used in orthodontics recently. Nitride coatings were added to orthodontic wires to aid in surface hardening while epoxy electro coating provided improved esthetics. The epoxy coating on the wire surface helped in reducing the corrosiveness of the wire[8].



- **Uniform Corrosion:** Uniform corrosion is considered an even attack across the surface of a material and is the most common type of corrosion.
- **Pitting Corrosion:** Pitting is one of the most destructive types of corrosion and is a localized form of corrosion. Pitting is dangerous because it can lead to failure of the structure with a relatively low overall loss of metal.
- **Crevice Corrosion:** It is also a localized form of corrosion and usually results from a stagnant microenvironment in which there is a difference in the concentration of ions between two areas of a metal.
- **Inter-granular Corrosion:** Inter-granular corrosion can be caused by impurities present at these grain boundaries or by the depletion or enrichment of an alloying element at the grain boundaries.
- **Stress Corrosion Cracking (SCC):** Stress corrosion may result from external stress such as actual tensile loads on the metal or expansion/contraction due to rapid temperature changes.
- **Galvanic Corrosion:** It is the degradation of one metal near a joint or juncture that occurs when two electrochemically dissimilar metals are in electrical contact in an electrolytic environment.

➢ **Corrosion under Normal Oral Condition:**

In 1999, Hera Kim and Jeffery Johnson[8] studied if SS, TMA and NiTi-epoxy or nitride coated wire inhibit corrosion of the wire. The surface changes were evaluated using SEM device and it showed that maximum amount of corrosion was found on TMA wires followed by SS wires and least on NiTi-epoxy coated wires. This maybe because the epoxy coated NiTi is protected from the environment which lowers the corrosive potential.

Yasuyuki Yonekura et al[10] **in 2004** proposed in his study that Ti archwires exhibited higher resistance to corrosion than Co-Cr and SS wires and this may be due to the presence of protective oxide layer in the surface of Ti wires. The removal of this protective film leads to an increase in the corrosion rate for orthodontic wires; more metal ions may be released from the archwire end. The materials were measured using potentio-dyanamic polarization measurements. From their study, it was concluded that maximum amount of friction was seen in TMA wires which may be due to the wear of passivating layer and also manufacturing defects. Similar type of study was done by SR **Harish Kaushik et al**[11] **in 2001,** in which 2 types of orthodontic wire taken were NiTi and Cu-NiTi. The materials were tested under UTM for mechanical testing and hence it was concluded that the maximum cracking was observed under NiTi archwires when compared with Cu-NiTi wires. The maximum amount of corrosion was shown by TMA wires followed by Timolium then Titanium-Niobium and lastly SS wires when tested under SEM for surface evaluation. The Titanium-Niobium showed prominent striations and ridges with occasional voids whereas stress cracking corrosion was seen in SS wires as quoted by **K Pradeep Babu**[12] in his investigation. Corrosion evaluation can also be done with the use of Atomic Force Microscopy as stated by **Atia A. Yousif et al**[13] **in 2016.** In their results, the SS wires were found to be the smoothest because least surface corrosion was found on the surface, and SS wires showed lowest frictional coefficient and lowest sliding resistance followed by TMA and lastly the Cu-NiTi wires. This may be due to the micro cavity formed as a result of pulling out some particles. Their study concluded that correlation exists between surface roughness and friction.

- **Corrosion under different temperatures:**

Mauricio Tatsuei Sakima et al[14] **in 2006** evaluated the effect of corrosion and force level of NiTi archwires at 5 different temperatures between 30°C and 40°C. The force level is directly proportional to the frictional characteristics to the wire. The force is measured from Force System Identification apparatus. The results showed that Cu-NiTi has lowest and constant force level at 35°C when compared to NiTi wires. This is in accordance with the other studies done by **Luca Lombardo et al**[15] **in 2013,** where they investigated the effect of temperature 55 °C and 5°C on corrosive properties of NiTi wires and it was found that the forces expressed by NiTi wires increases with an increase in temperature and also corrosion was significantly increased and vice versa. **In 2020, Luca Friedli et al**[16] assessed the temperature influence on the chemical and mechanical properties of NiTi, Cu-NiTi and SS wires. When the wires were stored for 24hrs in an incubator before their testing at 4 different temperatures, the result showed that Cu-NiTi exhibited more stable behavior when stored at all temperatures, whereas SS wires showed constant result i.e no change observed when tested under different temperatures. A study done by **Prem Vishva Natarajan et al**[17]**,** stated that on increasing the temperature of the artificial saliva and chlorhexidine, the corrosion of SS wires when immersed in artificial saliva and chlorhexidine was decreased.

- **Interventions using mouthwashes or dentifrices:**

Corrosion of the TMA and NiTi alloys in fluorinated mouthwash solutions can also occur via hydrogen embrittlement. This phenomenon can also be responsible for the degradation of the mechanical properties of titanium based alloys. **In 2004, Kazuyuki Kaneko et al**[3] evaluated the effect of the fluoride solution on the mechanical properties of SS, NiTi, Beta-titanium and Co-CrNi wires after immersed in acidulated fluoride gel (APF gel). The NiTi and Beta-titanium wires tensile strength decreased because wires absorbed substantial amount of hydrogen whereas SS and Co-CrNi tensile strength was affected little bit when immersed in fluoride solutions. SEM assays for characterization of fluoride treatment effects on wires revealed that NiTi and CuNiTi wires suffered corrosive changes on surface topography. **Marcelo Bighetti et al**[18] **in 2012,** evaluated the surface of Ti when they were exposed in different concentrations of NaF at the concentration of 0.05% for 3min and 0.2% for 3 min. SEM testing was done for the surface characterization and the result showed that use of 0.05% NaF solution on titanium is safe whereas 0.2% leads to the surface corrosion making it rough. **Jaherch Hosseinzadeh Nik**[19] subjected SS and NiTi wires in the Chlorhexidine solution and measured the frictional force using Universal Testing Machine and surface roughness was measured using AFM and SEM. The SEM photographs revealed that NiTi wires were readily susceptible to corrosion when compared with SS wires immersed in Chlorhexidine solution. The study was helpful in evaluating the correlation that existed between the frictional forces of stainless steel archwires which increased significantly in artificial saliva, and that of β-titanium archwire decreased when compared with the dry condition.

Arash Azizi et al[20] where they mentioned the properties of rectangular NiTi wires, which are more prone to corrosion when immersed in fluoride containing solutions is in the accordance with the study done by Putt el al[21] who reported the direct effect of temperature on the surface of wires when exposed to fluoride solutions. The pH effect on orthodontic wires corrosion has been widely studied. **In 2003, Huang et al**[22] measured the amount of ions released from NiTi wires immersed in artificial saliva with different pH values as a function of time. They concluded that the amount of released metal ions increased with immersion time in all conditions and that the amount was greater when more acidic solutions were involved.

Viera Zatkalikova et al[23] when analyzed the rate of corrosion on metal alloys on increasing the fluoride concentration found that corrosion rate decrease with an increase of fluoride content. Their study concluded that fluoride has an inhibitive effect on the local corrosion of SS; this may be due to formation of stable metal-fluoride complexes, which may strengthen the surface passive film and prevent its breakdown.

CONCLUSION

The orthodontic archwires are exposed to intra-oral environment which is corrosive due to the presence of normal saliva, difference in pH and temperature. The effect of corrosion leads to discoloration of wire, leaching of ions into the oral cavity, degradation of physical and mechanical properties which may also lead to increase in frictional properties of the wire. These corroded wires may also sometimes leads of failure or breakage of orthodontic wires during the treatment resulting in delay of the orthodontic treatment as well as failure of treatment. These broken wires may also sometimes lead to trauma. During orthodontic treatment for the maintenance of hygiene and for the control of white spot lesions different types of prophylactic agents have been prescribed for the patient. The corrosive effect of different prophylactic agents has been proven over time and again on orthodontic archwires. Halides in the prophylactic agents can modify the metal surface and may result in corrosion which decreases the mechanical properties of wire.

The material surface roughness can lead to an increase in its frictional properties and may further lead to material failure. The use of dentifrices or prolong use of mouthwashes may corrode the properties of these wires. The increase in frictional forces can reduce the orthodontic force by 50% or more thereby reducing the quality of the treatment. The increase in frictional forces also causes an increase in treatment duration.

From the literature we can conclude that SS wires are least corrosive wires when compared to NiTi, TMA wires even in normal oral environment as well as when subjected to different dentifrices.

Thus it can be very well concluded that corrosion being an important factor during orthodontic treatment, to reduce this effect the maintenance of oral hygiene and regular change of wires is recommended and judicious use of the type of wires as well as prophylactic agents during the orthodontic treatment is recommended

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